

THE GULIYA ICE CAP, CHINA: RETRIEVAL AND RETURN OF A 308-M ICE CORE FROM 6200 M ALTITUDE

Bruce KOCI and V. ZAGORODNOV

*Polar Ice Coring Office, University of Alaska Fairbanks,
Fairbanks, Alaska 99775-1710, U.S.A.*

Abstract: Drilling techniques and equipment used for retrieval and return of a 308-m ice core from a remote area of China are discussed. High resolution climatic records from remote regions of the planet are possible only if the core is continuous and of high quality. In this instance retrieval of core from over 200 m below the firm ice transition required a switch of drill type from electromechanical to thermal. Working at extreme altitude and bringing the core back in a frozen state across one of the warmest regions on the planet placed additional burdens on equipment, personnel, and logistics. Solutions to these problems, improvements for future projects, and implications for retrieving continuous deep cores in regions with limited logistics are discussed.

1. Introduction

In 1983, a program of coring low-latitude, high-altitude glaciers was begun with the successful drilling of two cores (154 and 163 m) to bedrock on the Quelccaya Ice Cap in Peru. Since then, three cores have been drilled to bedrock on the Dundee Ice Cap in China. Favorable results from these cores have now been supplemented by a single 308-m core to bedrock (with shallow supporting cores) on the Guliya Ice Cap in western China.

A standard 200-m drilling system developed by PICO in 1982 was modified to accept the 400 m of cable needed to drill the deeper ice at this location (PROENZA *et al.*, 1990). Since the system was originally designed to be transported anywhere a person can walk, no modifications other than expanded winch capacity were required. The additional flexibility of being able to use electromechanical and electrothermal means of coring ensured meeting core quality requirements necessary for continuous long records in remote areas of this planet.

This project was the most ambitious to date in demands of personnel and equipment because of remoteness, drill depth requirements, and altitude of more than 6300 m. None of the above caused insurmountable problems and the season proceeded to completion without incident. Drilling equipment and ice cores have been returned to the U.S.

2. Project Description

The Guliya Ice Cap is located in a remote area of western China on the Tibetan Plateau. Access is achieved by driving all-wheel-drive trucks to the glacier front, which is located 170 km northeast of the nearest road. The base camp lies at 5400 m with the summit of the ice cap at 6700 m.

Three sites were selected as potential drill sites: the summit and two sites at lower elevation. Since the summit was logistically most difficult, we decided to drill the two lower (and deeper) sites first, allowing time for acclimatization and time to see if the snowmobiles would continue to function. As a result, the three summit holes with depths of approximately 100 m each were placed on a lower priority.

Prior to drilling, 7000 kg of equipment, core boxes, and fuel had to be hauled up the steep slope that provides access to the glacier. Four stages were required to pull the equipment up to an area level enough for snowmobiles to take over. Since the winch was originally designed to pull itself or the drill onto glaciers, this presented no problem and saved a great deal of man-hauling effort.

Drilling at Site 1 proceeded slowly because of heat and sand nodules within the ice. A 7-m drill shelter was used because of anticipated wind conditions on the ice. Despite a 1-1/2-m hole in the dome top, temperatures ranged between 20 and 26°C inside. As a result, the drill heated up on the surface, causing chips to freeze to the drill. We cured this by drilling at night. Additionally, sand blown onto the snow surface coalesces into nodules within the ice. While the drill cut through frozen sand, the process dulled cutters which resulted in poor drilling progress and fine chips which potentially can stick the drill.

At a depth of 82 m horizontal layering was cut by a discontinuity. The departure from horizontal layering continued to a depth of 92 m where drilling ceased. Loss of a continuous record and danger of re-sticking the drill were reason enough to depart the area.

Drilling at Site 2 commenced with the same heat problems but greatly reduced sand nodule dimensions. We lived on-site and drilled early morning and as late at night as possible. Electromechanical drilling provided good core quality until a depth of 197.5 m, where the core began to fracture as a result of bubble pressure within the ice. From 197.5 m to the bottom, a thermal ethanol drill was used (ЗОТКОВ, 1979). Core quality was good but small because debris within the ice slows the penetration rate, causing excess heat to melt the core and hole wall. Drilling proceeded smoothly and without incident to the bottom at 307.5 m. Addition of ethanol to the hole caused no problems with the core, and the hole remained open throughout the five days of drilling. Temperatures ranged from -6° to -3°C at 200 and 300 m, respectively. No evidence of thermal shock cracking was observed in the cores or in practice cores taken in -16°C ice near the surface. Finally, a 36-m core was drilled the last day to check repeatability between cores. The equipment and ice cores were then man-hauled off the glacier.

3. High-Altitude Power Generation

Global programs of paleoclimate reconstruction require specialized power-generating equipment, because the glaciers from which the data are derived generally lie above 5000 m. Standard engine-driven generators, because of the reduced power at altitude, become inadequate to the task. Since weight and fuel consumption are critical factors in transport to remote areas with difficult access, several options have been explored. Additionally, the use of fuel cells, because of their potentially high thermal efficiency, should be explored further.

Generally, the standard manufacturer-supplied 2 to 3% power loss per 300 m does not apply. A better approach for these high altitudes is to use standard atmospheric density vs.

altitude as a first approximation of power loss. Power available is then obtained by multiplying known engine power at sea level by the ratio of density at altitude divided by sea-level density. Other corrections have to be made for latitude (atmospheric pressure decreases near the poles) and ambient temperature.

For this discussion, we will break considerations into two parts: below and above the 500-mb level (5500 m). At altitudes above 5500 m, commercially-available power plants lose their ability to provide adequate power. Specifically, a 5-kW generator which requires 6 to 7 kW engine power shows performance degradation above this altitude. As a result, engines of high horsepower/weight ratio are required to keep the logistics burden manageable. Since the maximum weight of any single piece should be less than 20 kg, 2-stroke cycle engines are the only alternative, although fuel cells may replace them eventually. The Guliya Ice Cap at 6700 m has been, and will probably be, the only ice cap where such engines are necessary. Hence, normal operations below the altitude require an engine/alternator combination that can be separated, realizing that individual component weight will rise to 40–50 kg for two pieces of equipment. Another consideration is the availability of solar power, which is always preferable if sufficient sunlight is available.

For locations at lower elevations in Greenland and Antarctica (3000 to 4000 m), supercharging of diesel engines is desirable to avoid the barbaric and simplistic practice of merely buying a larger engine and de-rating it. Up to 30% of the fuel remains unburned using this procedure. This is not to be confused with turbocharging, which avoids the problem.

To summarize, the selection of a power system for remote high-altitude drilling is a complex matter relying heavily on the configuration of each specific site. Since these sites are difficult to get to and field operations are carried out at the edge of human ability to function, overall logistics burden and piece size are severely limited. Altitude, access difficulty, and local climate are key components in power source selection. Since the drill winch may be required to move all project equipment through “difficult” terrain, normal drilling parameters are no longer valid. Hence, each system is sized for a specific project. Unfortunately, there is no easy formula.

Fortunately, other power systems exist such as solar, wind, and potentially, fuel cells. Solar has been used successfully on three projects and is particularly applicable where power demands are high, such as in thermal drilling. It is limited to daytime drilling, although energy-storing schemes may be useful, and is also limited to clean conditions. The weight of fuel saved on a project usually exceeds the weight of the solar panels.

4. Drilling the 308-m Hole

Past projects in this global sampling scheme never required holes in excess of 200-m depth. Glacier temperature profiles provided clear evidence of whether electromechanical or thermal drills were best suited to complete the job. In this instance, presence of cold ice and firn required use of an electromechanical drill until hole closure or deteriorating core quality forced a conversion to thermal or thermal/ethanol drilling. In addition, presence of wind-blown sand damaged cutters of the electromechanical drill at a rapid rate, and also slowed progress while drilling thermally.

Drilling a global array of ice cores to be used as ground truth for climate models

requires a continuous core with few breaks to provide high resolution of the record for at least the past few centuries. To provide this record, in particular when the cores exceed 200 m in length, requires a combined use of drill types, thermal and mechanical.

A standard PICO 4-inch electromechanical drill equipped with chevron-shaped cutters was used to drill the first 195 m. Core quality was good but began to show signs of breaking up at 175 m, which is approximately 170 m below the firn/ice transition. By 195 m, the core was fragile, difficult to saw, and often experienced exfoliation while relaxing. Hole closure at this point was also a problem, requiring constant reaming to avoid sticking the drill. One result was excessive chips, which adversely affected drilling and limited core retrieval. Drilling proceeded very slowly in the last meters, requiring 15 min to complete an 80-cm run. The fine chips resulting from this procedure also increased the danger of sticking the drill. At this point, core retrieval was less than 10 m per day. Most drilling was accomplished at night to keep the drill cold.

Conversion to thermal-ethanol drilling required three hours and proceeded using a thermal-ethanol drill left from the Ross Ice Shelf Project (ZOTIKOV, 1979). Drilling rate picked up immediately, and generally, cores were retrieved in 1- to 1.2-m continuous



Fig. 1. Schematic of the antifreeze thermal electrical drill (ATED):
1) drilling bit; 2) core catchers; 3) piston; 4) cable.

lengths. Ethanol concentration over a wide range of temperatures has been calculated by MOREV and YAKOVLEV (1984) and is discussed by ZAGORODNOV in a separate paper in this symposium. The curves appear to be accurate since slush formation was minimal and no signs of ethanol penetration were observed at the grain boundaries.

Lack of penetration has been confirmed in the core analysis now being performed by Lonnie THOMPSON at Ohio State University (pers. commun., 1993). A cross-section of the drill and plunger are shown in Fig. 1. Drilling ceased at 308 m when a hard object was encountered. Debris within the ice slowed progress, but gentle pumping of the drill provided an adequate solution. The improved drill design presented by ZAGORODNOV *et al.* (this symposium) is expected to further enhance the ability to drill thermally in dirty ice.

The ethanol water solution represents an ideal drill fluid for this type of drilling once the ice is relatively warm. The curves presented before illustrate this. We were able to drill the entire 113 m of core with less than 150 l of ethanol. The hole remained open throughout drilling and at no time offered excessive resistance to raising or lowering the drill. Hole temperatures were quickly measured prior to thermal drilling, recording temperatures of -6°C at 190 m, which was extrapolated to -3°C at 308 m.

5. Systems Approach

Drilling at extreme altitude in a near-space environment with long, often-complicated logistics lines places restrictions on the project that go beyond what is required under normal circumstances. Since humans and their machines are operating close to the edge of what is possible, everything must function well and minimize the logistics burden. To date we have not encountered any two glaciers that have the same characteristics from either the drilling or a logistics standpoint. Hence, system flexibility is also a necessity. Finally, enough redundancy must be built into all systems to guarantee a 99% probability of success.

The Guliya coring was the most ambitious of any of the past remote drilling operations. Atmospheric pressure in the 400-mb range proved difficult for humans and air-breathing machinery. Solar power was not considered feasible because of monsoon thunderstorms and anticipated warm conditions for electromechanical systems. Snowmobiles were of limited use and finally failed due to lack of power. Finally, we had to winch and man-haul 7000 kg of equipment, fuel, shelter, and life support up the glacier. Most of this, plus 2000 kg of ice core, then had to be man-hauled back down and transported to Urumqi over 160 km of non-roads plus four days on questionable roads.

The core was transported in a frozen state across the Tarim Basin, which is one of the hottest places on the planet. It was then flown to Beijing and air-freighted to Ohio State without subjecting any core to melting.

We now have a basic system that is robust and that will work anywhere on the planet with a variety of power sources. The system includes a drill that functions for over three months but which weighs less than 100 kg. Core boxes developed for these projects are strong, light, and effective. They are now used extensively in polar regions also.

Drilling fluid is the heaviest item that must be considered in any project that requires going beyond 200 m. A single hydrophobic fluid possesses some desirable characteristics, but in these instances, and perhaps for environmental reasons, the use of ethanol is an

alternative that should be considered particularly in ice above -20°C where the logistics burden can be reduced by a factor of five.

The processing line is a critical part of coring projects, particularly if used in conjunction with the ability to go back with a whipstock and re-sample critical zones of the core (ZAGORODNOV *et al.*, 1994a,b). Drill and drill-hole size can then be kept as small as practical. Additionally, carrying large volumes of core from uninteresting sections within the glacier is avoided and can be replaced with core through sections where remarkable events occur. Finally, preliminary analysis in real time checks observations at the source where questions can be answered on-site. If necessary, unanswered questions can be dealt with by re-coring zones in question.

It is our belief that no single coring system can provide the flexibility necessary to adequately address all the different conditions encountered in these global programs. However, a drill system that includes both mechanical and thermal drilling means that will work with a variety of power sources allows the science to proceed with greatest chance for success. The drill system must be backed up by good analytical capabilities, power generation, hole fluids, support structures, and core shipping mechanisms that provide the greatest possible amount of information from each project. In addition, systems that are smaller, lighter, and more efficient will provide the information with least impact on the object being studied, preserving it for future investigations if they are deemed necessary. There is a time restraint since all of the low-latitude, high-altitude glaciers seem to be in a state of rapid retreat.

References

- MOREV, V. A. and YAKOVLEV, V. M. (1984): Liquid fillers for boreholes in glaciers. CRREL Spec. Rep., **84-34**, 133–135.
- NAGORNOV, O. V., ZAGORODNOV, V. S. and KELLEY, J. J. (1994): Effect of a heated drilling bit and borehole liquid on thermoelastic stresses in an ice core. Mem. Natl Inst. Polar Res., Spec. Issue, **49**, 314–326.
- PROENZA, L. M., KELLEY, J. J., KOCI, B., SONDERUP, J. and WUMKES, M. (1990): Shallow and deep ice coring devices developed by the Polar Ice Coring Office. Polar Ice Coring Office, **CP-90-2**, University of Alaska Fairbanks.
- ZAGORODNOV, V. S., KELLEY, J. J. and NAGORNOV, O. V. (1994a): Drilling of glacier boreholes with a hydrophilic liquid. Mem. Natl Inst. Polar Res., Spec. Issue, **49**, 153–164.
- ZAGORODNOV, V. S., KELLY, J. J. and KOCI, B. (1994b): Directional drilling. Mem. Natl Inst. Polar Res., Spec. Issue, **49**, 165–171.
- ZOTIKOV, I. A. (1979): Antifreeze-thermodrilling for core through the central part of the Ross Ice Shelf (J-9 Camp), Antarctica. CRREL Rep., **79-24**, 12 p.

(Received April 20, 1993; Revised manuscript received December 21, 1993)